91602
new 82-10

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if Reproduced in Whole or in Part

SCALE MODEL SIMULATION OF IMPACT OF A RAIL LOCOMOTIVE COUPLER ON THE IRRADIATED FUEL TRANSPORTATION CASK

Report No. 89-197-K

R.M. Zane and J.D. Tulk
Special Projects & Computing
Applied Mechanics Section
Mechanical Research Department

ABSTRACT

Ontario Hydro has developed a transportation cask for large-scale shipments of irradiated fuel from CANDU reactors. This package was licensed for use on public highways by a series of nine metre drop tests, in accordance with the AECB Regulations for radioactive materials transport. The tests described here go beyond the regulatory requirements and were designed to demonstrate that the cask would be capable of surviving the impact of a large freight locomotive traveling at high speed.

The test featured a seventh scale model of the cask striking a seventh scale model locomotive at 105 km/h (65 mph). To achieve this impact velocity, a small rocket motor was used to help accelerate the cask model. The test showed that the locomotive, despite its size and heavy construction would absorb most of the impact, while the cask would escape relatively unscathed.

job	file	date	report no.
21-250-461	825.122	November 16, 1989	89-197-K

91602
new 82-10

90-03515/

ontario hydro
research division

EXECUTIVE SUMMARY

SCALE MODEL SIMULATION OF IMPACT OF A RAIL LOCOMOTIVE COUPLER ON THE IRRADIATED FUEL TRANSPORTATION CASK

J.D. Tulk and R.M. Zane

Ontario Hydro has developed a transportation cask for large-scale shipments of irradiated fuel from CANDU reactors. This package was licensed for use on public highways by a series of nine metre drop tests, in accordance with the AECB regulations for radioactive materials transport. The tests described here go beyond the regulatory requirements and were designed to simulate a collision between a freight locomotive travelling at 105 km/h (65 mph) and an Ontario Hydro irradiated fuel transport cask (IFTC). The test was carried out to resolve the question of whether or not a stiff, blunt "projectile" - such as the coupler on a fast-moving train-could penetrate the wall of the IFTC.

The test featured a seventh scale model of the cask striking a seventh scale model locomotive at 105 km/h (65 mph). To achieve this impact velocity, a small rocket motor was used to help accelerate the cask model. The test showed that the locomotive, despite its size and heavy construction would absorb most of the impact, while the cask would escape relatively unscathed.

JC

job	file	date	report no.
21-250-461	825.122	November 16, 1989	89-197-K

ontario hydro
research division

To Mr. D.W. Souther
Manager, Nuclear Engineering
H10 A1

SCALE MODEL SIMULATION OF IMPACT OF A RAIL LOCOMOTIVE COUPLER ON THE IRRADIATED FUEL TRANSPORTATION CASK

1. BACKGROUND

The experiment described in this report simulated a collision between a freight locomotive traveling at 105 km/h (65 mph) and an Ontario Hydro Irradiated Fuel Transport Cask (IFTC, Figure 1). The test was carried out to resolve the question of whether or not a stiff, blunt "projectile" - such as the coupler on a fast-moving train - could penetrate the wall of the IFTC. The experiment was initiated and primarily funded by the Radioactive Materials Transportation Unit of the Nuclear Materials Management Department.

The IFTC is designed to be a very robust, high integrity structure. It is designed to withstand impact loads from a variety of situations, including a nine metre drop onto a flat unyielding surface, as mandated by the Atomic Energy Control Board (AECB) and International Atomic Energy Agency (IAEA). The IFTC design had been shown to comply with this requirement in a series of drop tests/1,2/. However, it was noted that the standard nine-metre drop test has a terminal velocity of about 13 m/s or 48 km/h while rail or road traffic may move more than twice as fast.

It is generally held that the AECB/IAEA drop test is severe compared to road or rail accidents because the "target" for the drop test is so hard that it absorbs very little of the kinetic energy at impact. By comparison, most real obstacles or projectiles will "give" and dissipate impact energy. This argument is supported by experimental results reported by the Central Electricity Generating Board of Great Britain/3/. The CEGB carried out full-scale experiments on "Magnox" fuel casks that included nine-metre drops and a spectacular 160 km/h (100 mph) train collision test. In these experiments, the damage to the cask from the drop test was more severe than from the train collision, even though impact velocity was much higher in the latter case.

The results of the CEGB demonstration were very encouraging for the IFTC's designers, particularly since the Magnox fuel cask and the IFTC are similar in many respects (both are thick-walled cuboid boxes with bolted lids). However, there are important structural differences between cask designs and between between British and North American locomotives that make it impossible to make a simple extrapolation from the CEGB results. These include differences in draught gear and frame design that have a significant effect on energy absorbing characteristics. Because of uncertainty about the relative stiffness and energy absorbing

capacity of the components that would participate in a train/cask collision, there was concern that a cask might suffer unacceptable damage. The test described in this report was designed to meet this concern.

2. EXPERIMENT DESIGN

2.1 Test Parameters

The experiment was intended to demonstrate whether a railroad coupler might inflict significant damage on the side of an IFTC as the result of a train/cask impact. The following conditions were assumed:

- The coupler was assumed to be mounted on one of the heaviest freight locomotives in regular service in Canada (176,000 kg).
- The locomotive is assumed to be traveling at 105 km/h (65 mph), above the railway freight speed limit, and equal to the top speed of this type of locomotive.
- The coupler is assumed to hit the cask at the centre of one of its long sides, which is considered to be the worst case situation for damage to the cask wall by a concentrated load. The face of the cask would be perpendicular to the direction of travel.
- The cask is assumed to be free to move as a result of the impact. It was also assumed that the impact would occur relatively quickly, so that cars in the train behind the locomotive would have negligible effect on the result.
- The cask is assumed to be fully loaded, with a total weight of approximately 34,700 kg.

2.2 Overall Test Design

Earlier in the development of the IFTC, a pair of seventh-scale models of the cask had been built for nine metre drop testing. One of these models was available and in good condition, so that this was an obvious starting point for this experiment. Seventh-scale also meant that the locomotive model was a practical size. Comparison of drop test results between seventh- and half-scale models have demonstrated that scale models can predict the effects of impact loading reliably, provided models are accurate replicas of the larger prototype. As was pointed out in Reference/2/, the smaller model is "stiffer" than the full scale version in the sense that vibration frequencies are higher. However, impact accelerations are also higher, with the net result that stresses and strains remain constant over a scale change.

To achieve proper scaling of impact energy (and hence strain energy in the experimental models) it is necessary to have the impact velocity in the reduced-scale experiment the same as impact velocity in full scale. Providing an impact velocity of 105 km/h (29 m/s) presented a challenge. Direct modeling of a railway (with the locomotive model moving horizontally) was rejected on the grounds of cost and complexity. A drop test from a tower is a simple and effective way to achieve medium velocities, but for the velocity required in this experiment, a free fall of at least 43 m is required. This was beyond the height of towers that were

conveniently available for the test, so a method was needed to increase acceleration beyond that due to gravity alone. We added a small downward-firing solid fuel rocket to the falling model to increase its terminal velocity.

We also had to decide whether to have the cask model accelerated into the train model or vice versa. These two approaches are kinematically equivalent, since it is relative velocity at impact and resulting transfer of momentum and kinetic energy between the two bodies that matters, not the absolute velocity of either participant. The cask model is much lighter than the locomotive model (100 kg vs. 500 kg) so that having the cask fall onto a stationary locomotive was far safer than the other way around.

In summary, the experimental setup was as follows (see Figures 2 and 3):

- The model cask was dropped from one of the horizontal arms of a disused transmission tower onto a train model mounted at ground level.

- The model was fastened to a frame structure that slid down a pair of guide wires. This ensured that the model coupler would hit the cask model at the centre of one of its long sides.

- A small rocked motor was mounted on the frame, aimed so that its thrust increased the downward acceleration.

- A seventh-scale model of a freight locomotive was suspended from the guide wires with clamps that were designed to break away with a force slightly above the dead weight of the model. This meant that the locomotive model was able to move upon impact.

- Immediately before the test, the frame, cask and rocket assembly was hoisted to the top of the guide wires. The moving components were suspended by a release hook. A special triggering system was designed to coordinate rocket firing and hook release.

2.3 Cask Model

The cask model was a seventh scale replica of the IFTC. Most of the major structural features (lid bolts, impact limiter, lifting trunnions) were reproduced quite closely, although some details (O-ring groove profiles, lid and vent ports, thread sizes) were changed or omitted to simplify manufacture. The most important difference, from the point of view of the rail coupler impact tests was that the body of the model cask was machined from a Type 304L stainless steel casting, while the full-scale IFTC body is forged. This meant that the yield strength in the model was lower that would be anticipated in full scale. We believe that this adds a degree of conservatism to the tests.

Figure 4 is a photograph of the cask, before the test. The body of the cask is painted yellow, while the impact limiter is dark green. These colours were chosen so that the cask model would stand out vividly from other test components.

2.4 Locomotive Model

As was mentioned earlier, the main objective of the experiment was to find out what damage a rail coupler travailing at 105 km/h (65 mph) might do to the cask wall. Accordingly, the locomotive model was designed such that the coupler (complete with hinged knuckle), draw gear (a spring mounting arrangement for the coupler used to reduce shock loading during train shunts) and draw gear housing were modeled in some detail. The structural elements of the locomotive frame were also scaled carefully to ensure that stiffness and strength characteristics were modeled. Other major components (diesel engine, alternator, wheel bogies, fuel tank and air compressor) were represented by steel masses bolted to the frame at the appropriate locations. These components don't participate in the impact except as masses, so that it was not necessary to model them in detail. The sheet steel outer bodywork of the locomotive was represented as a steel box structure. Small components and light-weight structures (hand rails etc.) were not modeled.

Table 1 shows the major components of a typical freight locomotive with their approximate masses. The components which were modeled (scaled) have been highlighted and are graphically represented in Figures 5 and 6. Figure 5 also shows two vertical plates welded onto the bedplate of the locomotive near the front and defined as "collision posts". These are designed to offer the locomotive operators some measure of protection in the event of head-on collisions. Because of the size and location of these plates, they were included in the model.

Rail cars other than the locomotive were not modeled. The British experiment had shown that the main transfer of momentum and energy occurs very quickly after the impact - in effect before the shock of the collision had time to travel back through the locomotive to the rest of the train. This means that other train cars have relatively little effect on the dynamic forces experienced by the cask.

Figure 7 is a photograph of the front of the locomotive model, in position for the test. The coupler bar can be seen projecting from under the bed plate.

2.5 Tower and Test Set-Up

The tower used for this test was prototype 500 KV transmission tower located at the Kleinburg Research Facility. This tower was selected because of its size, location and because there were no transmission lines attached to it. Figures 2 & 3 illustrate this tower and the test set-up. Two 12.7 mm diameter wire cables ran vertically from the middle arm of the tower to an adjustable steel frame which was firmly anchored to the ground. The ground frame enabled the two cables to be precisely aligned. Tension on the cables was adjusted by turnbuckles between the cables and the ground frame. The Road Cask model was attached to the guide cables by a sliding guide frame. The guide frame also held the rocket tube (Figure 8). The guide frame and road cask model were hoisted up the cables by a lifting rope running over a pulley on the tower arm (Figure 9). When released by the release hook, the road cask, propelled by the combined effects of gravity and the rocket, accelerated down the guide wires and collided with the locomotive. The locomotive model was suspended on the guide wires to ensure accurate alignment.

Three systems were available to measure the velocity of the falling model. Both were attached to a pair of posts mounted in the ground next to the locomotive model. The first system used a pair photoelectric cells which started and stopped a high speed clock when the falling model interrupted light beams. Knowing the distance between the two beams enabled the velocity to be calculated. The second velocity measuring system was more rudimentary and served as a back up should the first system fail. This system consisted of two trip wires which, when broken by the falling model, would send a signal to a storage oscilloscope. An additional velocity measurement system also existed in the high speed cameras used to document the test.

As a precautionary measure, a wall of timber and plywood was erected at the base of the tower. This wall was designed to offer some protection to the tower base in the event that the road cask model hit the tower after striking the locomotive.

It should be noted that in the interest of creating a realistic simulation of an actual train road cask collision, the test set-up was designed to allow the road cask and locomotive models to shear free of their respective constraints (guide wires) after impact. In an actual collision, there are no restraints (beyond gravity) to keep the locomotive on the tracks or to keep the road cask directly in front of the locomotive after impact. Both are free to fall clear of the track.

2.6 Rocket Firing and Release System

The solid fueled rockets used to assist gravity in this test were custom made for this project. The additional acceleration required to reach the desired impact velocity was calculated and a rocket providing a total impulse of 2,225 N.sec (500 lb.sec), with a total burn time of 1.67 sec was specified. This yielded an average thrust of approximately 1,332 N. (300 lb.). The manufacturer (Vulcan Systems) produced a rocket having a diameter of 52.4 mm (2 1/16") and a length of 584 mm (23"). The solid fuel propellant weighed 0.976 kg (2.15 lb.) per motor. The rocket was fired by electrical resistance type ignitors. A summary of the rocket characteristics is shown in Table 2.

The experiment was expected to do irreparable damage to the locomotive model so that it was essential that the first run be successful. One important requirement was that firing of the rocket motor and activation of the release hook suspending the guide frame and model had to be properly coordinated. The release hook could not be triggered until the rocket motor was fully ignited (if the rocket misfired, the impact velocity would be too low to meet our test objective). On the other hand, it was essential that the hook release immediately after the rocket fired (otherwise the burn might be over before the model reached full speed). It was also important for the test that all participants (camera operators, instrument operators) be able to delay the test should they have any problems with their equipment. A special control panel was developed to meet these requirements. The panel worked as follows:

- All test participants had a control box with a go/no-go switch connected to the main panel. If, at any point prior to the test a problem occurred with any of the participants equipment, they could switch to the "no-go" state and the firing circuitry would be disabled (Figure 10). When they were ready for the test, they switched to the "go" state, giving the control panel a green go-ahead signal. Only after all stations had "gone green" (Figure 11) was the firing circuitry ready to be armed and fired.

- Once the rocket was ignited, the release hook control circuitry became activated and took control of releasing the model. There were two system for releasing the hook supporting the model. When the rocket motor fired, the exhaust jet pushed up on a blast plate, activating a micro switch that released the hook and hence the model. The exhaust also burned through a filament stretched over the nozzle of the rocket. When the filament circuit opened, the release hook was activated.

- For safety reasons, the rocket motor ignitors were kept grounded up to the moment of firing to prevent accidental firing.

Ignitors were always inserted in the motors in pairs, in case one malfunctioned. A fire proof "bunker suit" was always worn when installing the ignitors (Figure 8).

The guide wires, guide frame, rocket motors, velocity measuring system and firing system were all tested in a series of "dry runs" which simulated the final tests, except that crude mock-ups were used in place of the cask and locomotive models.

2.7 Photography

No instrumentation was mounted on the cask model because of the long and unwieldy cabling that would have been required. Consequently, all information on cask response had to come from "post-mortem" examination of the cask and train models and photographic records taken during the event. Photographic coverage of the experiment was extensive and included a variety of high speed movie and video cameras (to provide a record of events during impact) and a number of motorized 35 mm still cameras (for high-resolution photographs).

A red and white checkerboard pattern backdrop was located directly behind the locomotive model. This provided both a contrasting background for photographs and a measuring aid.

3.0 RESULTS

As a result of meticulous preparation, thorough rehearsals and very good weather, the tests ran very well. The velocity measuring instrument confirmed that the impact velocity was 107 km/h (67 mph).

Figure 12 provides an overview of the test set up, moments after the model was released and the rocket motor triggered. The most obvious elements in this picture are the tower and guide wires, the red and white checkerboard backdrop located at the foot of the wires and the photographic equipment clustered around the test site. The cask model and rocket are visible approximately half way up the guide wires, while the locomotive model is the rectangular gray object between the guide wires, in front of the checkerboard backdrop.

3.1 Impact Sequence

Figure 13 is a photograph taken just before the moment of impact. Figure 14 was taken approximately 1/6 of a second later. From the high-speed movie and video records, we have pieced together a history of the collision, as follows:

Time (sec)	*Event*
0.000	Impact!
0.001	Draw gear springs compressed to full extent, coupler breaks out of draw gear box.
0.003	Cask strikes front of bed plate.
0.008	Bed plate bent back, cask strikes collision posts.
0.030	Cask has reached maximum penetration of locomotive model. Locomotive breaks clear of guide wires.
0.040	Locomotive model falls away from cask.

3.2 Post Impact Examination

3.2.1 Surface Damage

Figures 15 & 16 are photographs of the cask model, as it came to rest after the test. Scrape marks from the coupler and bed plate are clearly visible, while the impact limiter bears the impressions of the two vertical "collision posts" on the locomotive model. Beyond superficial marks though, there was no sign of significant damage to the cask.

Figure 17 is a photograph of the front of the locomotive model, post-test. The draw gear enclosure had been torn open and the coupler bar was separated from the rest of the model. The bed plate was bent back by the force of impact, up to a point where the structure became stronger because of the presence of the longitudinal frame, the collision posts and the block representing the front wheel bogey. Figure 18 shows the coupler bar where it came to rest, about 10 metres from its original location.

3.2.2 Lid Gap and Bolt Torque Changes

Post-test examination of the cask model showed that the gap between body and lid changed by between +.076 mm (+.003 inch) and -.05 mm (-.002 inch, that is, the gap increased by three thousandths of an inch at one point and reduced by 2 thousandths at another). The average gap change was +.02 mm (+.0008 inch). Bolt torques also changed as a result of the impact. Before the test, the bolts were all tightened to a torque of 2.83 Nm (25 in-lb). After impact, release torque varied between 0 (a loose bolt) and 4.52 Nm (40 in-lb). Average torque was 1.44 Nm (12.7 in-lb). Figure 19 is a graph of gap change and post-test bolt torque. Bolts were numbered sequentially around the perimeter of the model, with bolts 19 to 28 on the side where it coupler bar struck. This graph shows that both gap and bolt torque increased on the impacted side, while on the opposite side, the gap increased moderately, .025 mm (.001 inch) while the bolt torques were reduced. It appears that on impact, the lid slid sideways with

respect to the body, bending and stretching the bolts on the impact side (which would account for simultaneous increase in gap and torque) and stretching bolts on the other side (resulting in a loss of torque).

Changes in lid gap were small. By comparison, during the nine-metre drop test (top corner impact), the lid/body gap changed by an average .25 mm (.01 inch) and the average bolt torque dropped from 2.83 Nm (25 in-lb) to 1.13 Nm (10 in-lb). This supports the view that a 105 km/h (65 mph) collision between a cask an a locomotive structure is a less severe test of cask integrity than a nine-metre drop onto an unyielding surface.

3.2.3 Dye-Penetrant Examination

A post-test dye-penetrant examination of the cask wall, carried out in accordance with a standard Ontario Hydro procedure (NDE-5N), revealed no surface cracks (Appendix A). This confirms that the cask wall was not significantly damaged by the rail coupler impact.

4.0 CONCLUSIONS

The experiment described in this report simulated a 105 km/h (65 mph) collision between an Irradiated Fuel Transportation Cask (IFTC) and a freight locomotive. The test showed that the locomotive would suffer a great deal of structural damage from the collision. This means that a large proportion of the kinetic energy available before the collision is absorbed as strain energy in the locomotive and impact limiter. Damage to the cask model was limited, demonstrating that the IFTC is a very robust structure, capable of surviving very severe impacts without failing.

5.0 ACKNOWLEDGMENTS

This test required the combined efforts of many individuals in the Mechanical Research and Nuclear Materials Management Departments who's contributions are gratefully acknowledged. However, we would like to pay special tribute to Paul Nigol, Cy Naumenko, and Nayan Shah who's many evening and weekend hours assured successful completion of the project. We also thank Keith Buck and his staff for the high-quality photographs appearing in this report.

Approved by:

G.J. Clarke
Manager
Mechanical Research Department

Reviewed by:

J.A. Chadha
Section Head
Applied Mechanics Section

RMZ/JDT:cam

Submitted by:

R.M. Zane
Intermediate Technician
Applied Mechanics Section

J.D. Tulk
Special Projects and Computing
Applied Mechanics Section

REFERENCES

1. *Safety Analysis Report for the IFTC.*

2. J.D.Tulk, *Scaling Effects in Drop Tests on IFTC Models.* Ontario Hydro Research Division Report 88-275-K, December, 1988.

3. *The Resistance to Impact of Spent Magnox Fuel Transportation Flasks.* Papers presented at a seminar organized by the Institution of Mechanical Engineers, April, 1985, London England.

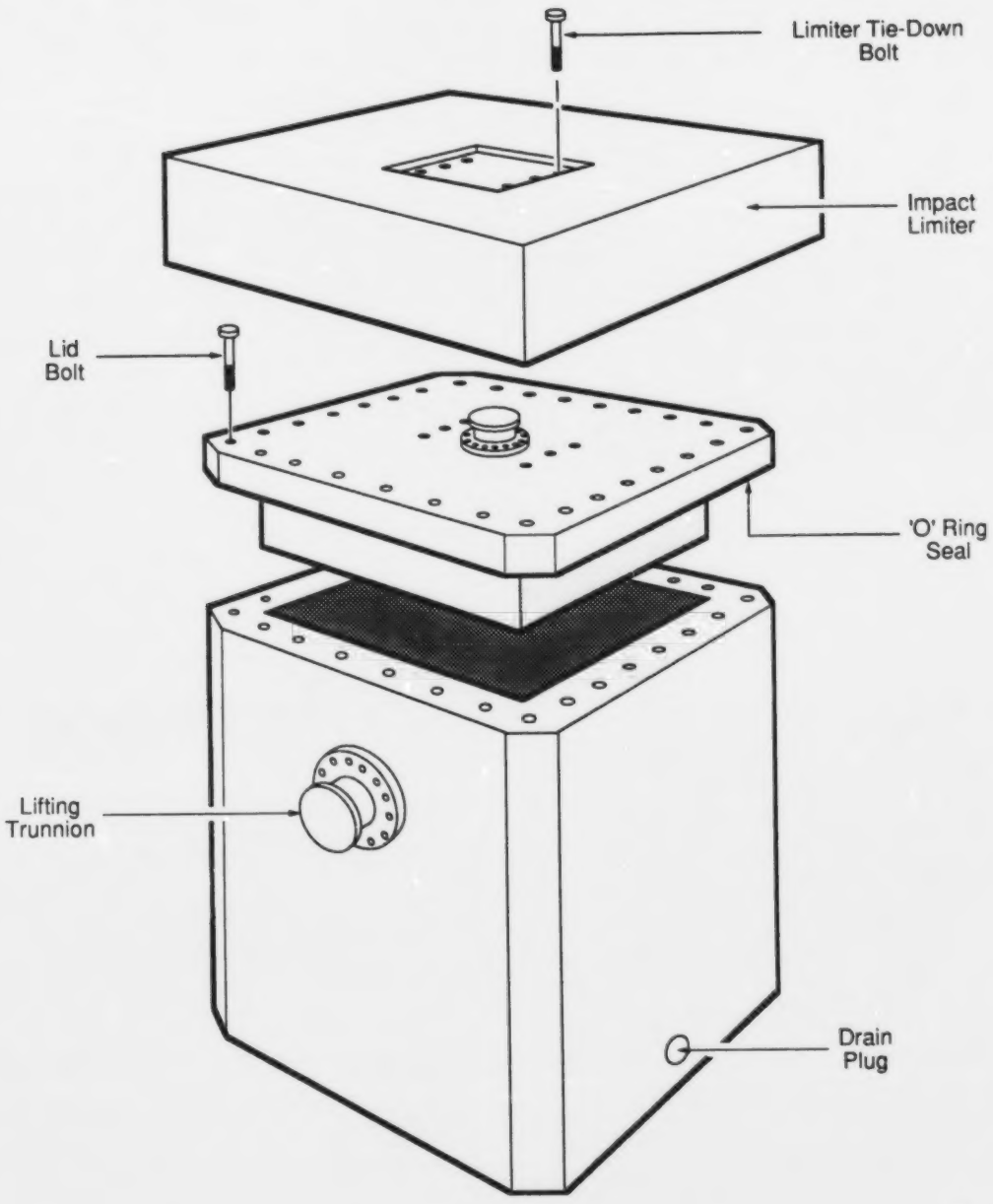


FIGURE 1

GENERAL FEATURES OF THE IFTC

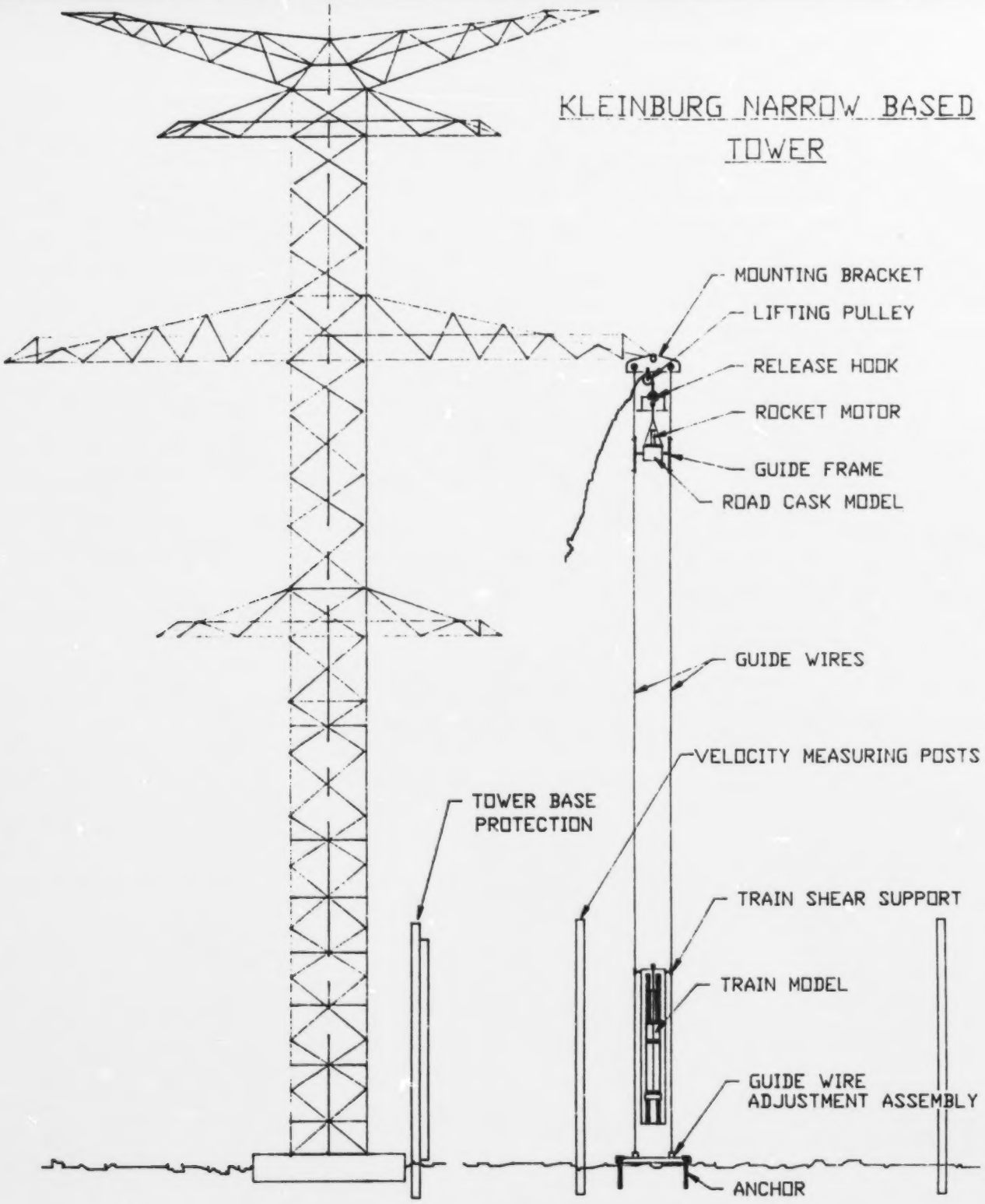


FIGURE 2

TOWER AND TEST SET-UP

89-197
180670-K6-RD

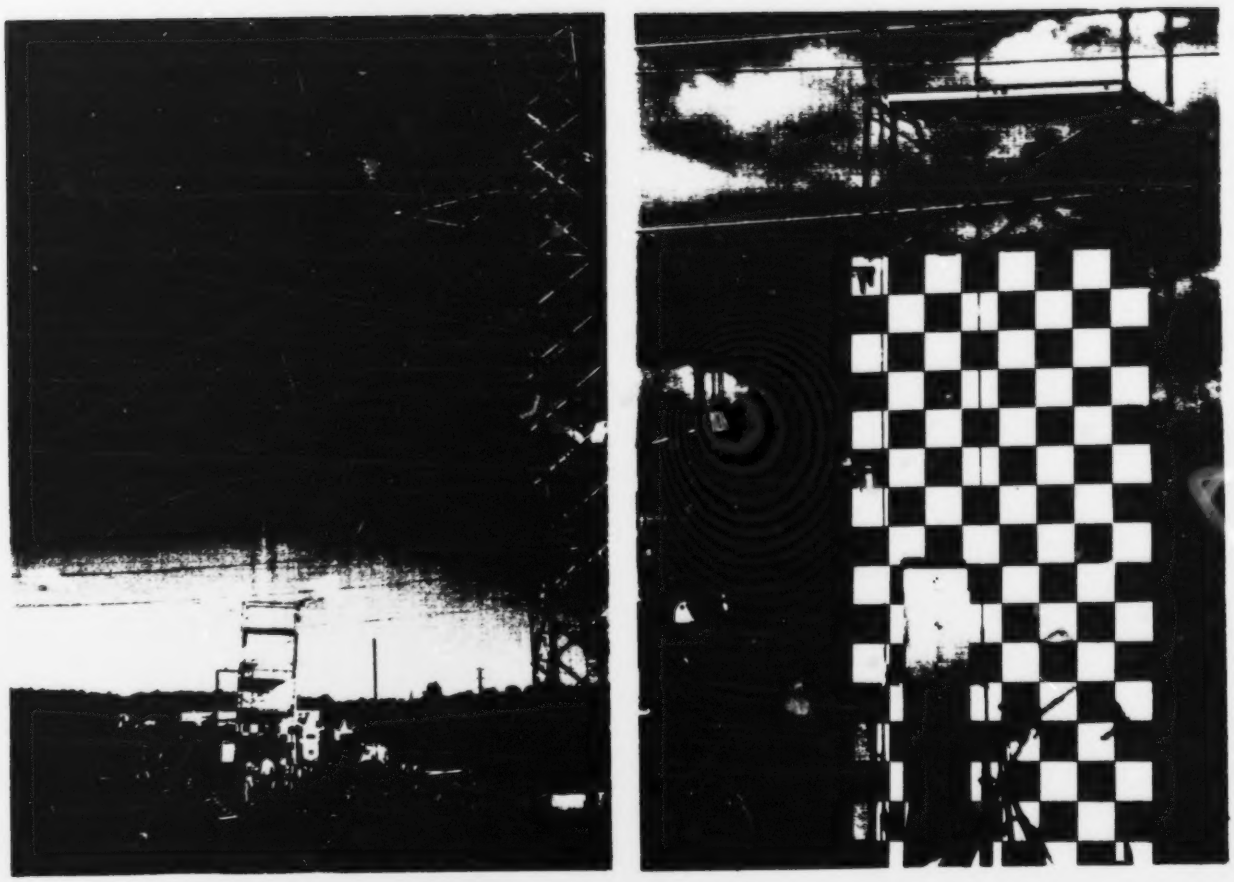


FIGURE 3

TOWER AND TEST SET-UP

FIGURE 4

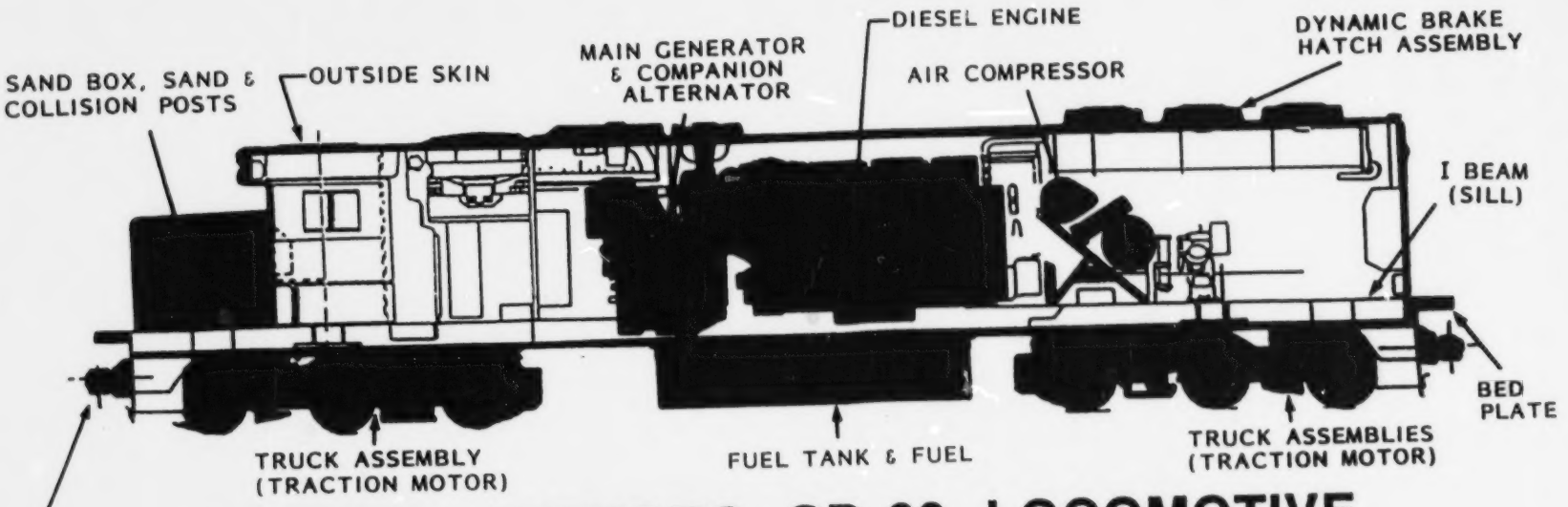
1/7TH SCALE MODEL OF THE IRRADIATED FUEL TRANSPORT CONTAINER

APPROXIMATE WEIGHTS

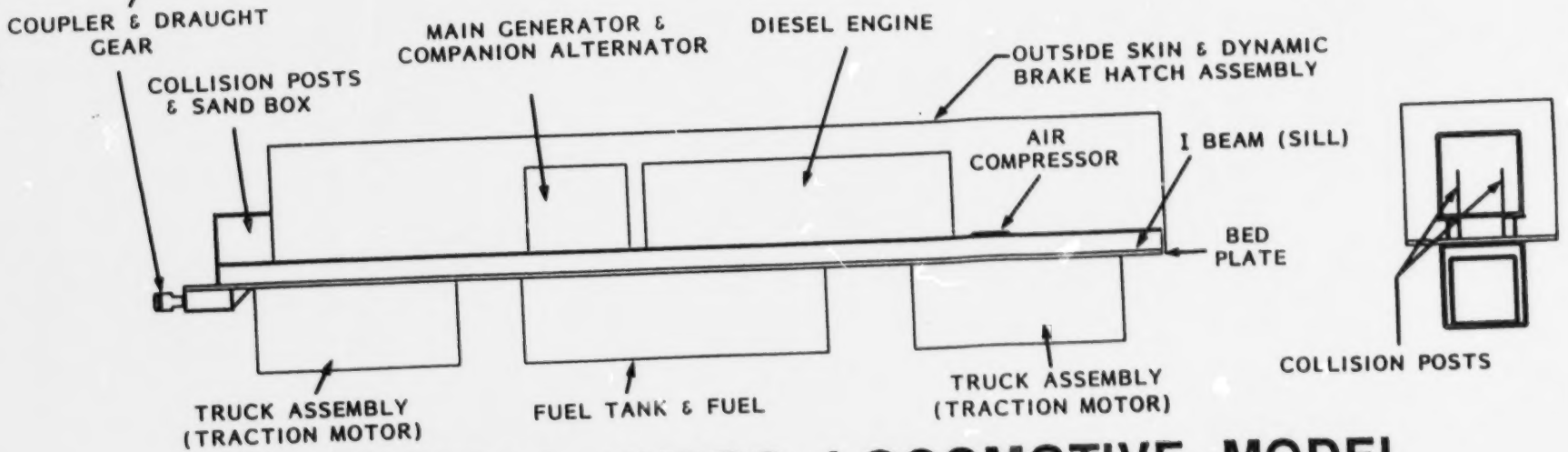
	Actual (kg)	1/7th Scale (kg)
Total Loaded Locomotive Weight on Rails	176,900	515
16-710G3 Diesel Engine	17,962	52.37
Starter Motor	35	.10
Starter Motor Bracket	26	.08
Engine Governor	54	.16
Turbocharger	816	2.38
Main Generator and Companion Alternator Assembly	7,438	21.69
Auxiliary Generator and Blower Assembly	454	1.32
Inertial Air Filter	272	.79
Inertial Filter Screen	16	.05
Inertial Filter Hatch (less filters)	227	.66
Fuel Tank (Basic)	3,175	9.26
Truck Assembly (HTC)	25,946	75.64
Traction Motor	2,722	7.94
Axle	601	1.75
Wheel 40"	485	1.41
Wheel 42"	590	1.72
Gear	186	.54
Bearing - Inner Race	15	.04
Air Compressor	1,055	3.08
Air Compressor Shaft	62	.18
Air Compressor Shaft Guard	31	.09
Air Compressor Coupling	22	.06
Lube Oil Cooler	383	1.12
Lube Oil Filter	227	.66
Fuel Pump Assembly	37	.11
Fuel Suction Strainer	4	.01
Fuel Filter	27	.08
Temperature Switch Manifold	9	.03
Load Regulator Vane Motor	16	.05
Dynamic Brake Hatch Assembly (grids, fan, motor)	1,134	3.31
Dynamic Brake Fan Assembly and Motor Assembly	454	1.32
Dynamic Brake Resistor Grid (each)	113	.33
Dynamic Brake Grid Shorting Contactor	16	.05
Radiator Fan Assembly (Q-Type, with Guard)	365	1.06
Radiator Core	147	.43
Cab Heater	32	.09
Storage Battery, Per Unit: Basic, Exide MS420	131	.38
Special Group KDZ3000	181	.53
SCR (Generator Excitation)	13	.04
Fuel	14,265	41.6
Sand	2,540	7.4
Outside Skin	4,263	12.4
Bed Plate	40,483	118
I-Beam (Sill)	3,157	9.2

TABLE 1

SUMMARY OF THE MAJOR COMPONENTS OF THE MODELLED SD-60 FREIGHT LOCOMOTIVE



GENERAL MOTORS SD-60 LOCOMOTIVE

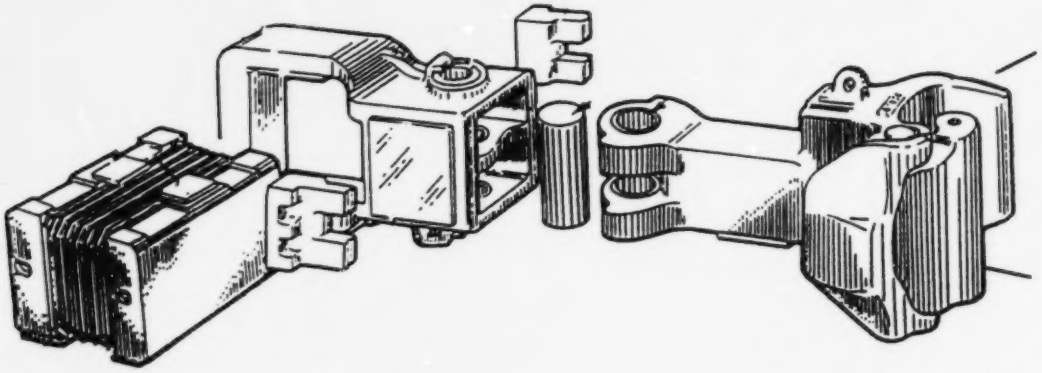


ONTARIO HYDRO LOCOMOTIVE MODEL

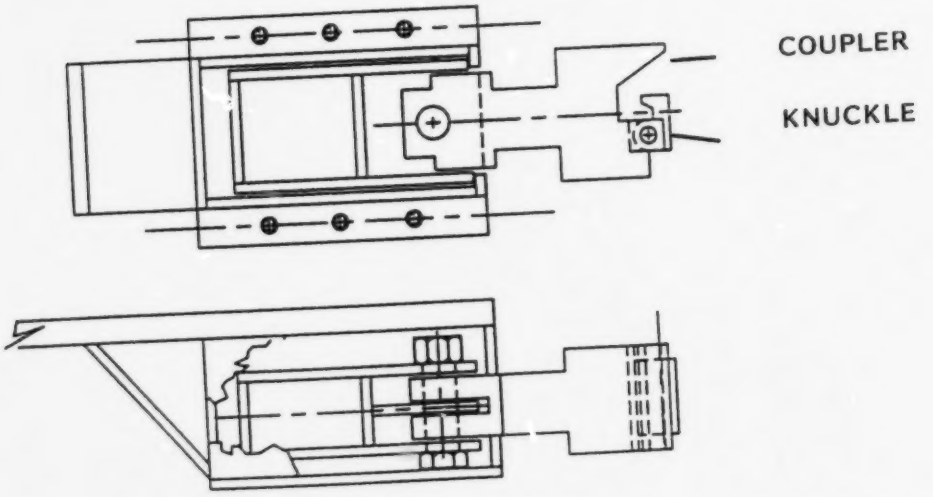
FIGURE 5

GRAPHICAL REPRESENTATION OF FULL SCALE FREIGHT LOCOMOTIVE AND MODELLED COMPONENTS

89-197
180674



NC-391 DRAWGEAR ARRANGEMENT DIASSEMBLED



ONTARIO HYDRO DRAWGEAR MODEL

FIGURE 6

COMPARISON OF FULL SCALE DRAWGEAR AND MODELLED DRAWGEAR

89-197
180675

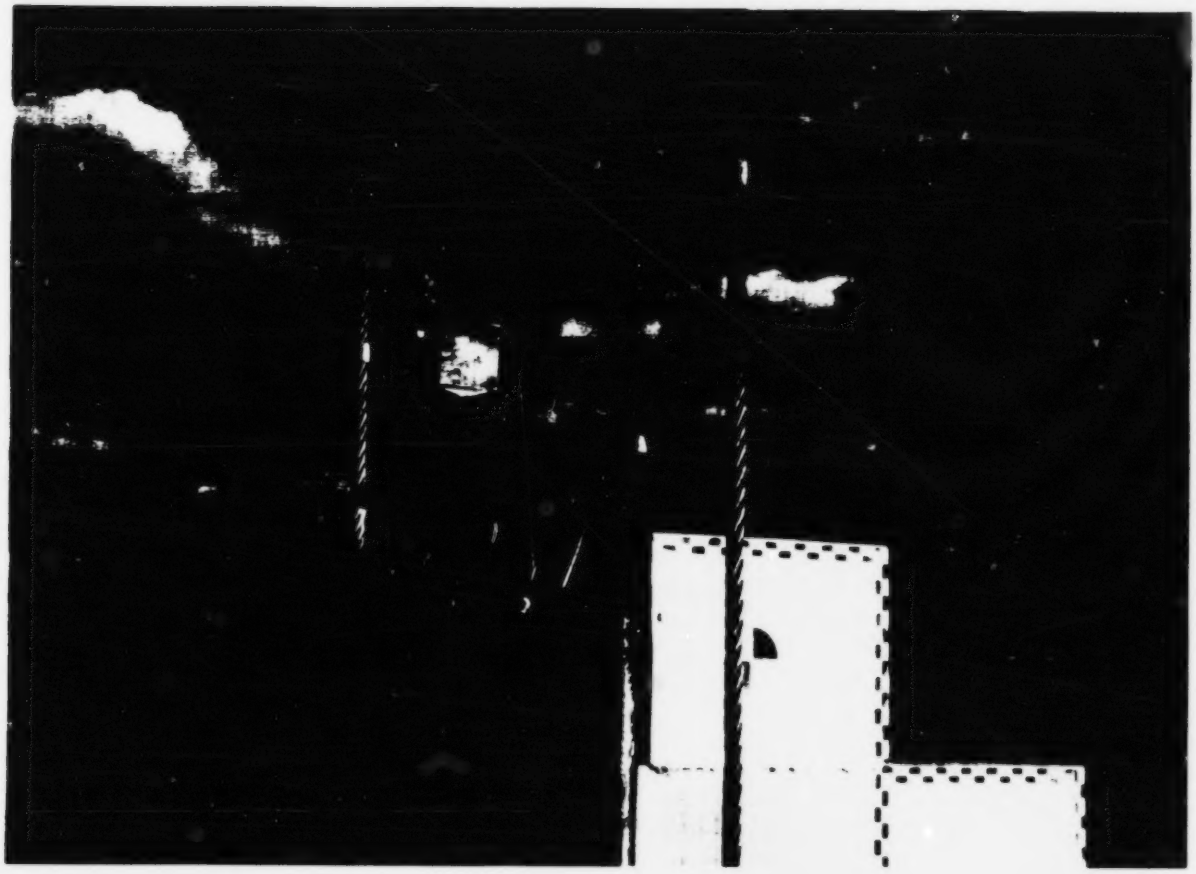


FIGURE 7

LOCOMOTIVE MODEL IN POSITION

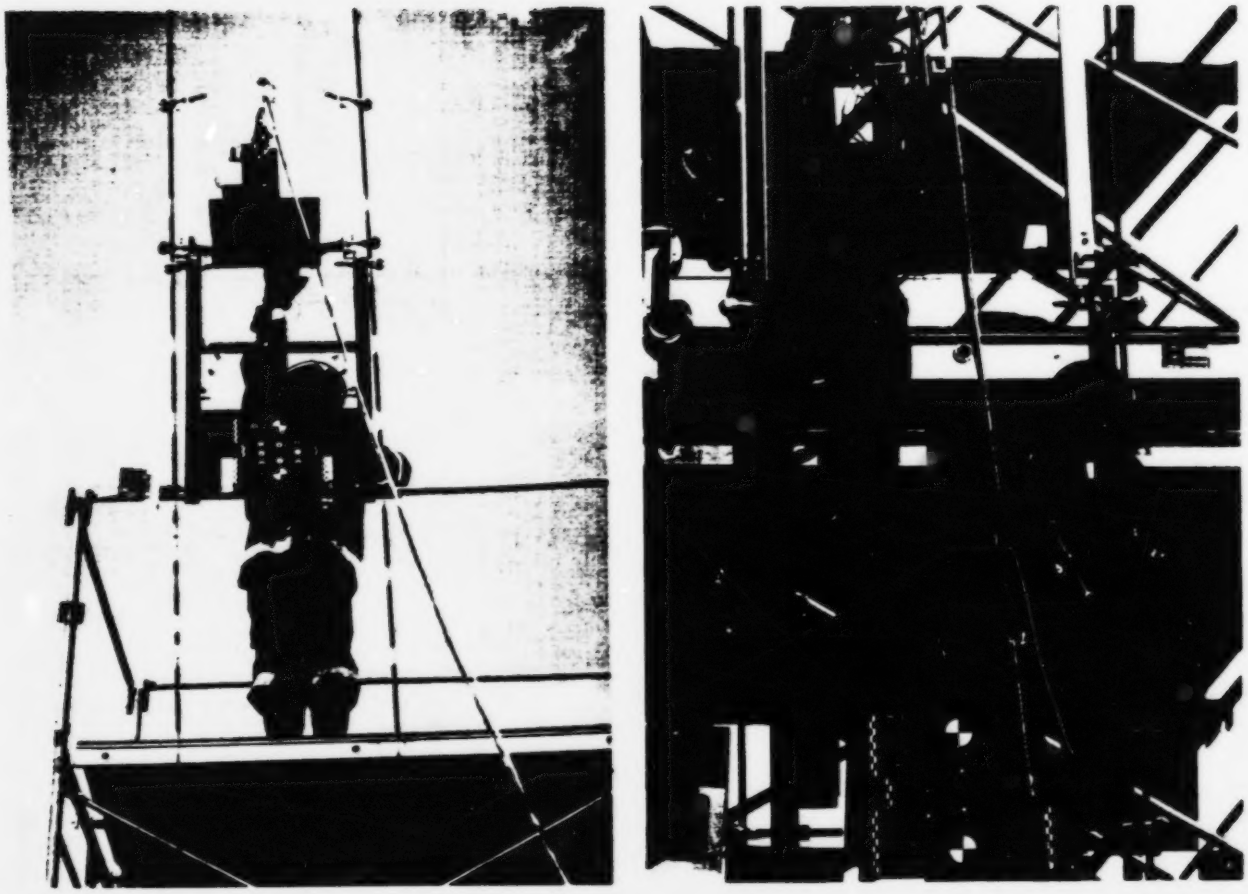


FIGURE 8

ROAD CASK MODEL ATTACHED TO GUIDE FRAME AND SUSPENDED FROM RELEASE HOOK
NOTE: THE BLACK TUBE IS THE ROCKET MOUNT

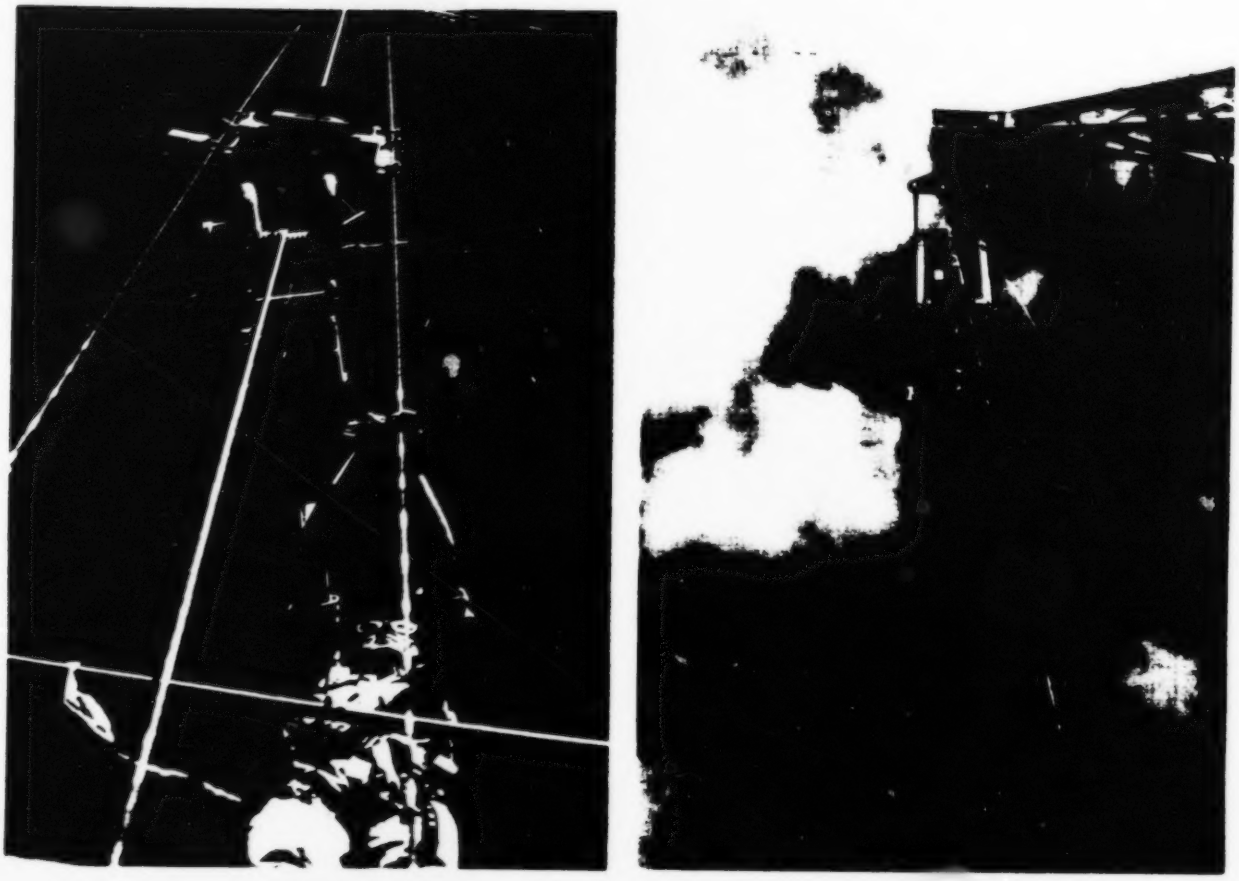


FIGURE 9

ROAD CASK AND GUIDE FRAME HOISTED UP ALONG GUIDE WIRES TO THE TOWER ARM

Rocket Motor Characteristics

Total Impulse	500 lb.sec
Average Thrust	300 lb
Burn Time	1.67 sec

Overall Dimensions

2 1/16" diameter

23" long

Propellant

(2) Segment BATES grain weighing 2.15 pounds per motor.
UN Classification: 1.3 c explosives

Rocket Motor Assembly

UN Designation: Rocket Motor - UN-0186

Availability

Commercially available by Vulcan System Inc. Since Approximately 1980.

No export restrictions enforced by US State Department.

Manufacturer

Vulcan Systems Inc
PO Box 6099
Colorado Springs, CO 80934

President: Scott Starkey Dixon

Competent Authority Approval (CA-860553)

TABLE 2

SOLID FUELLED ROCKET CHARACTERISTICS

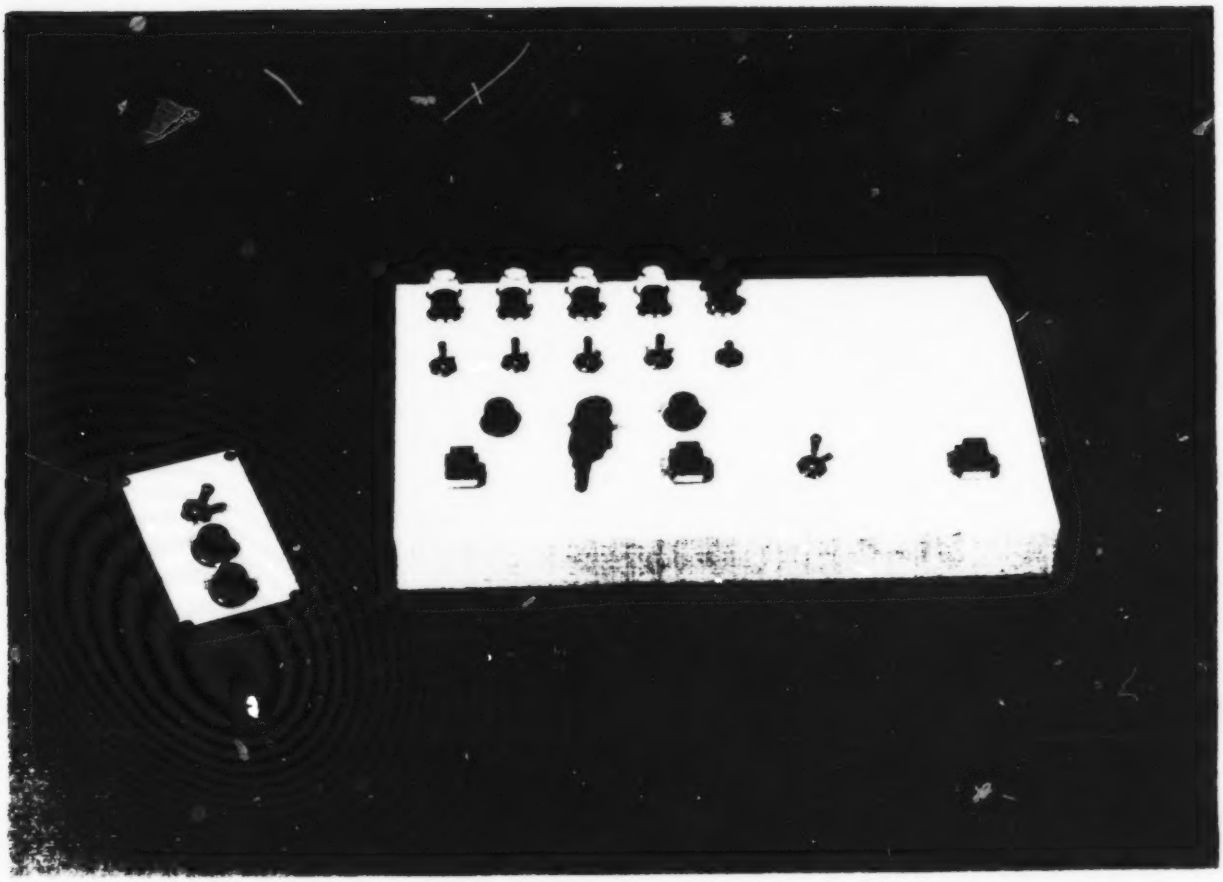


FIGURE 10

ROCKET FIRING AND RELEASE HOOK CONTROL PANEL
"STATION 1 IS NOT READY FOR FIRING"
"NO GO" STATE

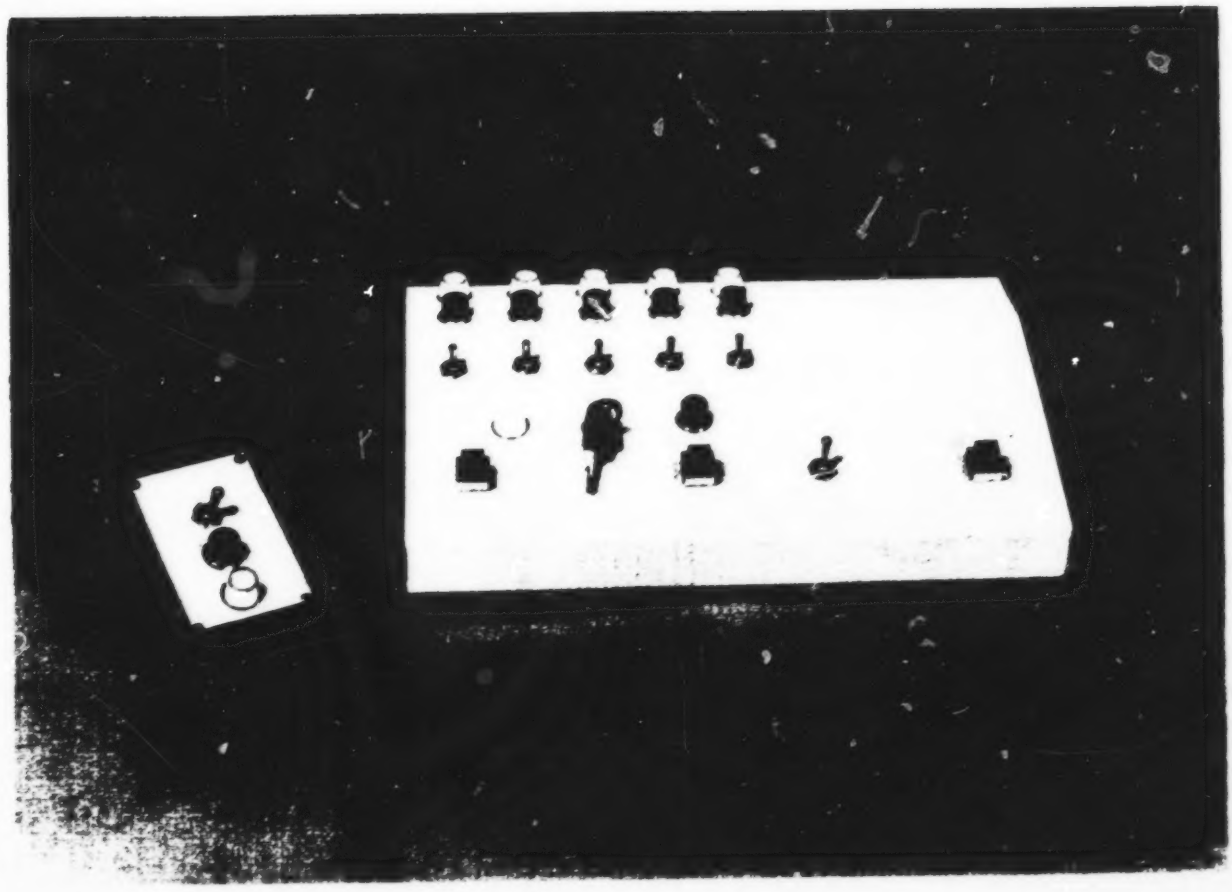


FIGURE 11

ROCKET FIRING AND RELEASE HOOK CONTROL PANEL
"ALL SYSTEMS GO"

FIGURE 12

OVERVIEW OF TEST SET-UP, MOMENTS AFTER ROCKET IGNITED AND MODEL RELEASED

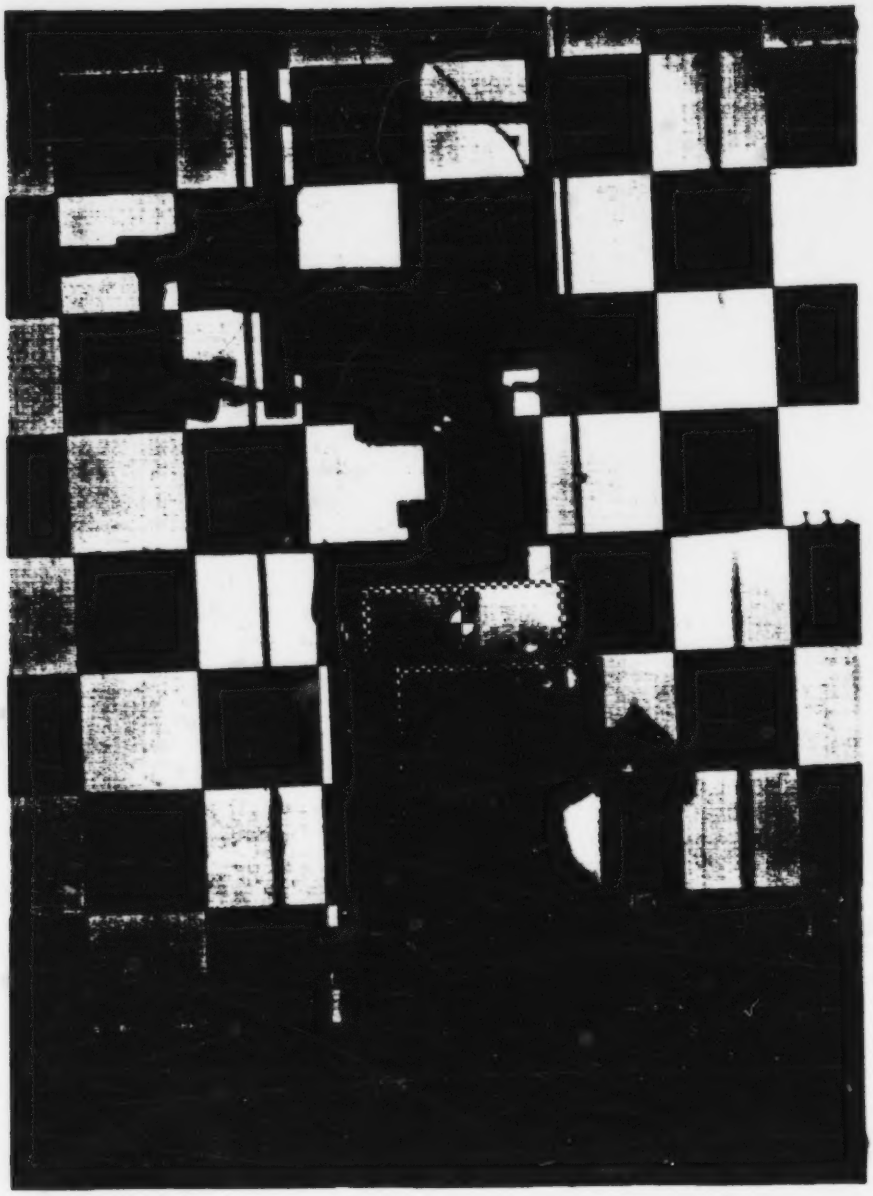


FIGURE 13

MOMENTS BEFORE IMPACT

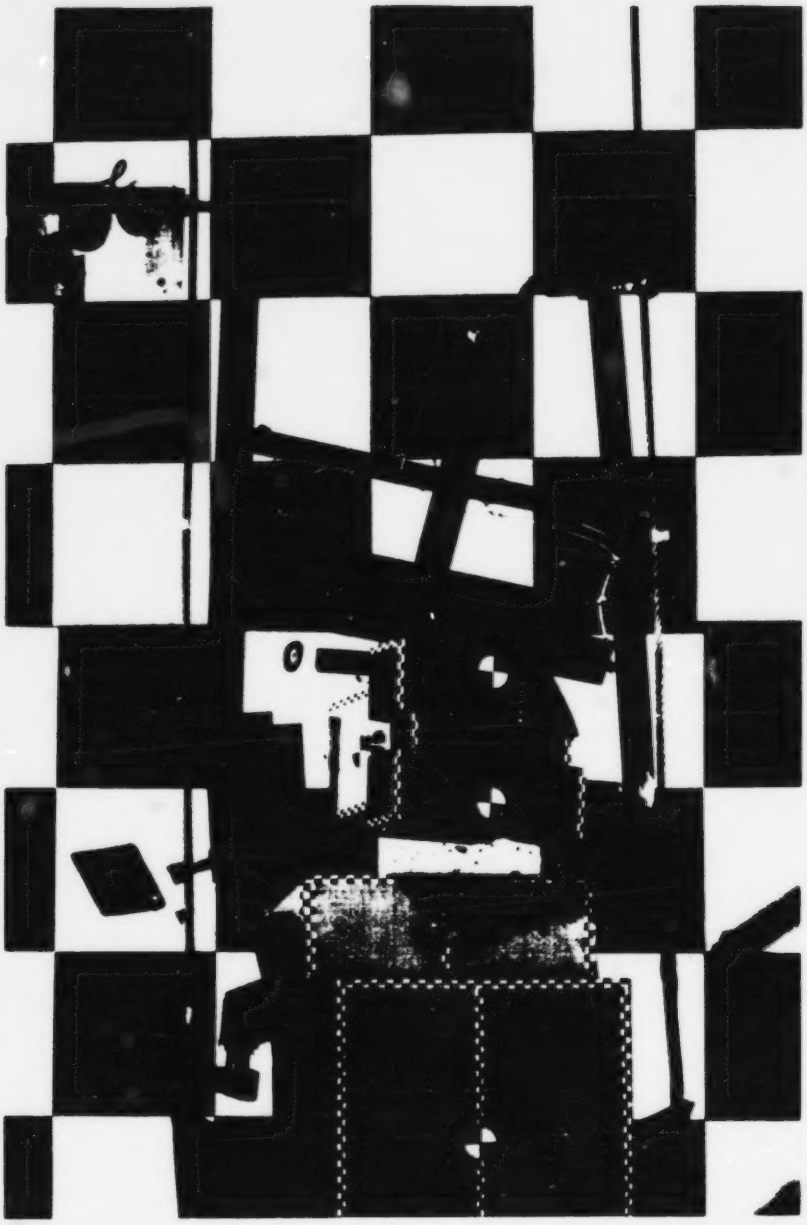


FIGURE 14

MOMENTS AFTER IMPACT

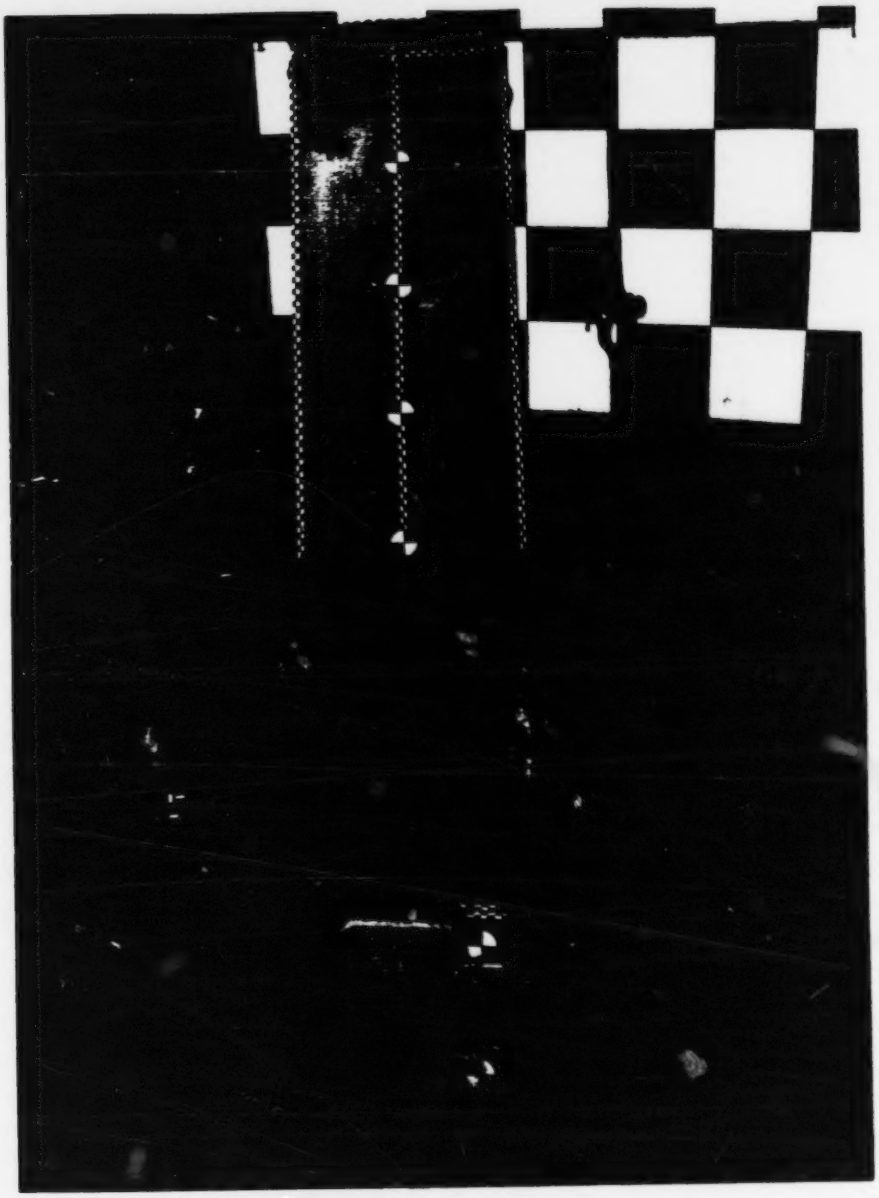


FIGURE 15

CASK AND TRAIN MODEL AT REST AFTER IMPACT

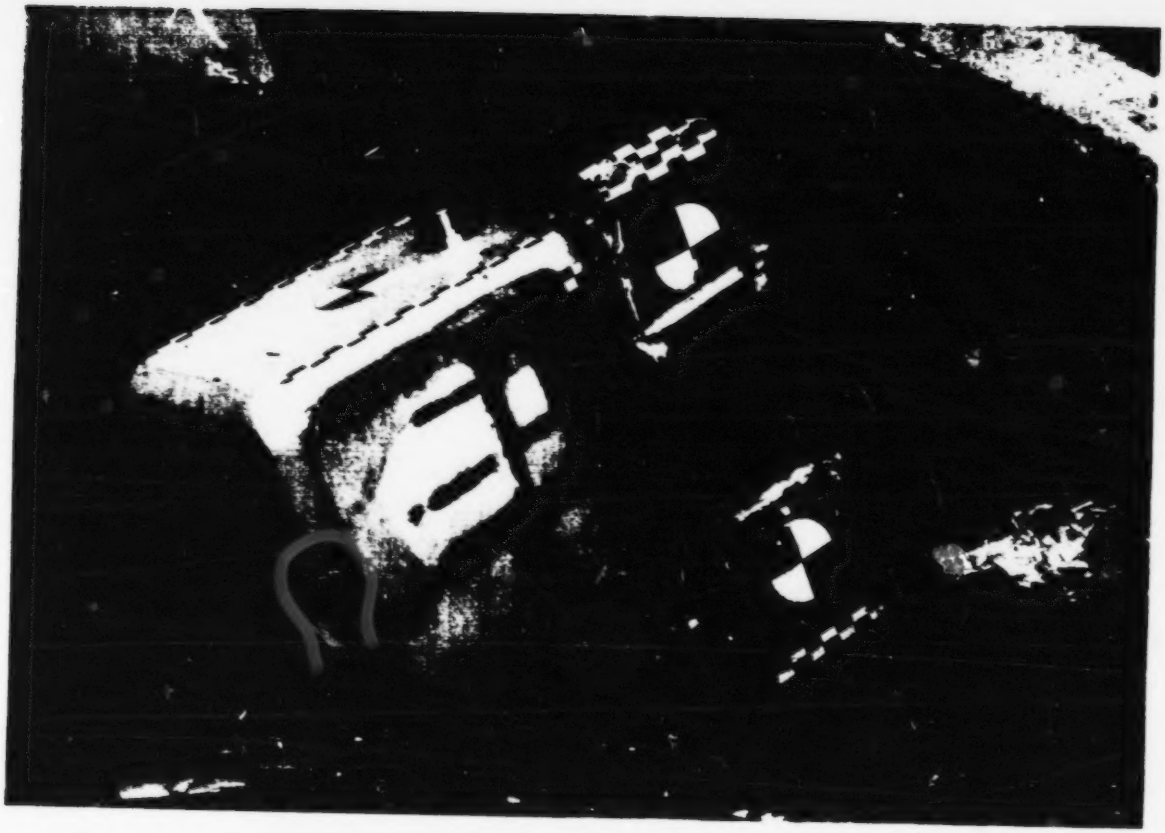


FIGURE 16

CASK MODEL AT REST AFTER IMPACT

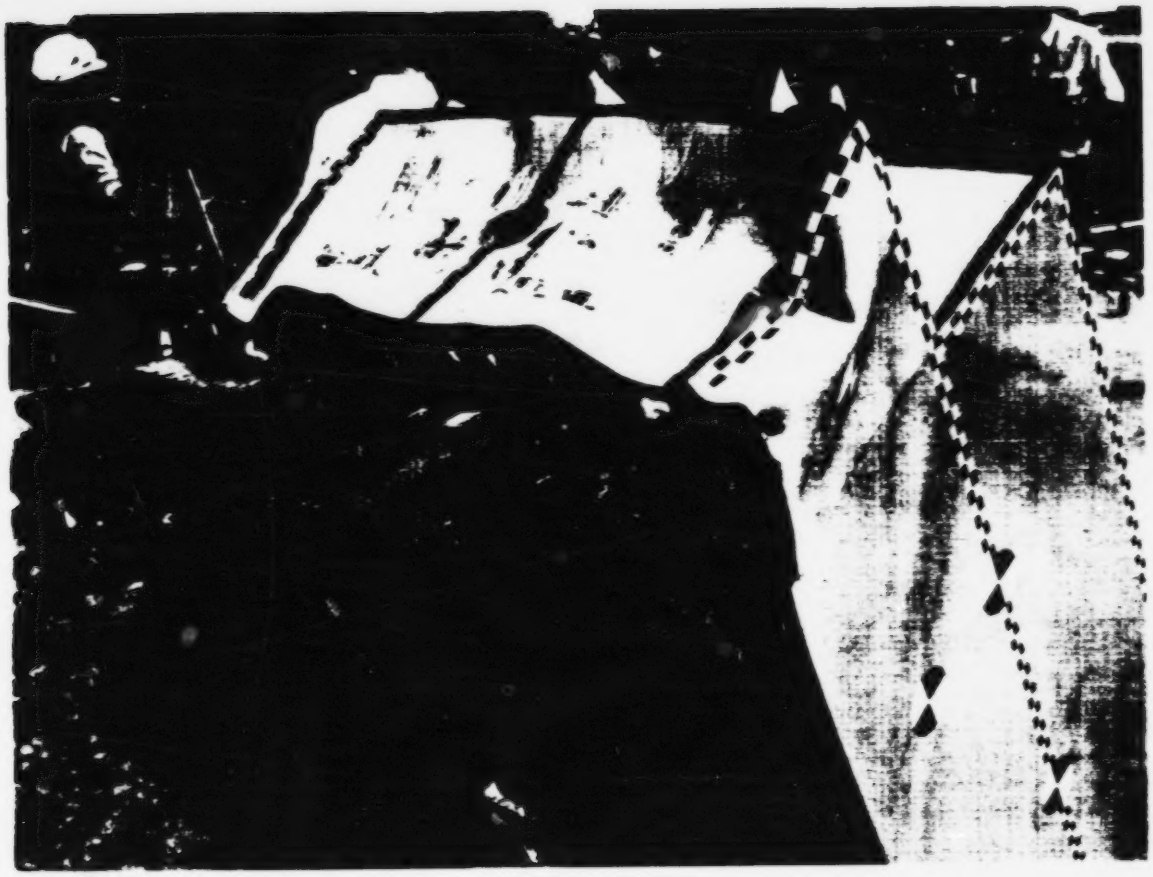


FIGURE 17

FRONT OF MODEL LOCOMOTIVE AFTER IMPACT

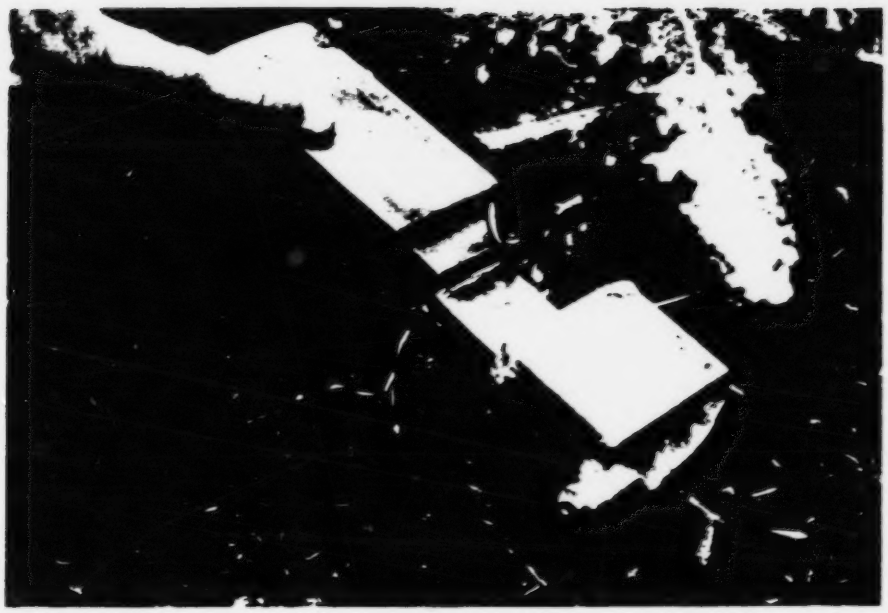


FIGURE 18

**COUPLER AFTER IMPACT WAS FOUND
10 METERS FROM ORIGINAL POSITION**

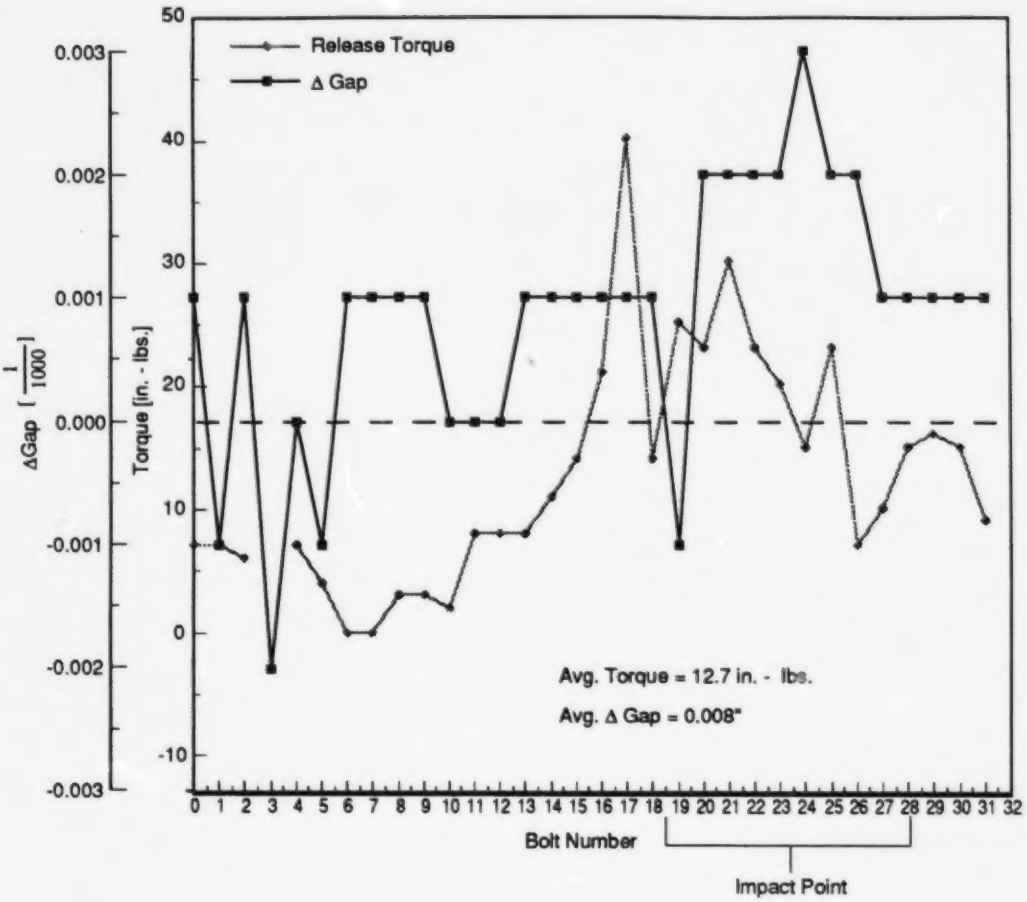


FIGURE 19

GRAPH OF BOLT RELEASE TORQUE AND ΔGAP VS. BOLT NUMBER FOR THE 1/7th SCALE ROAD CASK AFTER TRAIN IMPACT TEST

APPENDIX A

ontario hydro
research division

TO: Mr. R.M. Zane
Mechanical Research Dept
KB223

IRRADIATED FUEL TRANSPORT CONTAINER

T.R. Ryans

A 1/7th scale model of an irradiated fuel transport container (IFTC) was submitted to metallography by the Mechanical Research Department (Robert Zane) for dye penetrant testing. The liquid penetrant inspection was carried out in the metallography laboratory in accordance with Ontario Hydro procedure NDE-5N. The test failed to reveal any surface crack indications.

Approved by:

W.H.S. Lawson
Supervising Engineer
Metallurgy Section
Metallurgical Research Dept

Prepared by:

T.R. Ryans
Technician
Metallurgy Section

TRR:dr

DISTRIBUTION

Mr. R.M. Zane	Mechanical Research,KB223
Dr. W.H.S. Lawson	Metallurgical Research
Mr. R.J. Dudzik	Metallurgical Research
Mr. T.R. Ryans	Metallurgical Research

Official Record

job	file	date	report no.
21-370-061	823.3	February 7, 1989	MC89-1-K